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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G06F 15/68	A1	(11) International Publication Number: WO 90/07751 (43) International Publication Date: 12 July 1990 (12.07.90)

(21) International Application Number: PCT/US89/05702

(22) International Filing Date: 21 December 1989 (21.12.89)

(30) Priority data:
290,655 27 December 1988 (27.12.88) US

(71) Applicant: EASTMAN KODAK COMPANY [US/US]; 343 State Street, Rochester, NY 14650 (US).

(72) Inventors: KWON, Heemin ; 49 Hunters Run, Pittsford, NY 14534 (US). LIANG, Jeanine, Tsu ; 522 VanVoorhis Avenue, Rochester, NY 14617 (US).

(74) Agent: KAUFMAN, Stephen, C.; 343 State Street, Rochester, NY 14650 (US).

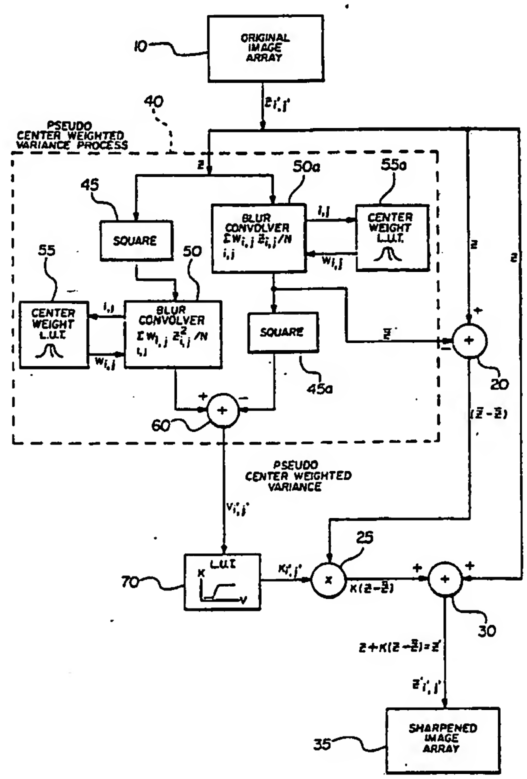
(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), ES (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent).

Published
With international search report.

(54) Title: UNSHARP MASKING USING CENTER WEIGHTED LOCAL VARIANCE FOR IMAGE SHARPENING AND NOISE SUPPRESSION

(57) Abstract

A pseudo center weighted local variance in the neighborhood of an image pixel determines the amplification factor multiplying the difference between the image pixel and its blurred counterpart before it is combined with the original image. The amplification factor is computed for each pixel in the image, and varies from a minimum value of about -1 when the center weighted variance is at a minimum value to some maximum value when the center weighted variance reaches a maximum value. The pseudo center weighted variance is computed by convolving the local neighborhood surrounding each image pixel with a kernel of center weights having a maximum value at the center pixel. The pseudo center weighted variance is the difference between the center weighted mean of the square of the local neighborhood of image pixels and the square of the center weighted mean. Both image sharpening and noise suppression is achieved in the same image by permitting the amplification factor to vary between a fraction of unity and greater than unity as the center weighted variance varies from a low value (uniform image) to a higher value (textured image).



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UNSHARP MASKING USING CENTER WEIGHTED LOCAL VARIANCE FOR IMAGE SHARPENING AND NOISE SUPPRESSION

BACKGROUND OF THE INVENTION

Unsharp masking is a well-known technique for enhancing the sharpness of processed images. Specifically, an original digitized image is stored from which a blurred version may be created by convolving it with a low pass filter (such as an unsharp mask). The difference between the blurred image and its original is multiplied by a factor K, and the resulting product is added to the original image to generate a sharpened image. The problem is how to compute the factor k by which the difference image is multiplied.

U.S. Patent No. 4,571,635 to Mahmoodi et al. teaches that the factor K is computed in accordance with a formula which depends upon the standard deviation of the image pixels in a local neighborhood. While this technique results in some improvement in the sharpness of the image, it would be desirable to obtain further improvement in image sharpness without proportionately amplifying the noise in uniform areas of the image.

SUMMARY OF THE INVENTION

A further significant increase in image sharpness is achieved without the expected proportionate increase in noise amplification in uniform areas of the image in the image process of the present invention. In the present invention, the difference image amplification factor K is not computed in accordance with the standard deviation as in Mahmoodi. Instead it is computed in

accordance with a pseudo center weighted variance process. Alternatively, a sharpened center weighted variance process is used in the invention to compute the difference image multiplication factor K. While the idea of center weighting an ensemble of image pixels in a local neighborhood has been disclosed by Kato et al., U.S. Patent No. 4,315,318, neither Kato et al. nor Mahmoodi et al. have considered such a computation in connection with the determination of the image difference multiplication factor K.

PSEUDO CENTER WEIGHTED VARIANCE

In the pseudo center weighted variance process of the invention, the difference image multiplication factor K is determined for each pixel in the original image in accordance with a pseudo center weighted variance computed for all pixels in a predefined neighborhood surrounding the pixel of interest. Computation of the pseudo center weighted variance, in accordance with the invention, is as follows: The pixels in the neighborhood are individually squared and then convolved with a kernel having the same dimensionality as the neighborhood, the kernel comprising a mask of center weight coefficients whose maximum value lies in the center of the kernel. Further, each pixel in the neighborhood is convolved (without being squared) with the same kernel of center weighted coefficients, and the result of the latter convolution is then taken as a whole and squared, the results of the squaring then being subtracted from the previous convolution. The resulting difference is the pseudo center weighted variance. The difference image multiplication factor K is then determined in accordance with a function that increases as the pseudo center weighted variance

increases.

Depending upon the steepness of the topology of the kernel of center weighted coefficients, the resulting sharpened image reproduces the edges in the original image with greater fidelity but without as much accentuation of noise in uniform image areas as might be expected. The image thus provides a significant improvement in the art.

DESCRIPTION OF THE DRAWINGS

The invention may be understood by reference to the accompanying drawings of which:

Fig. 1 is a block diagram illustrating the system of the invention;

Fig. 2a is a perspective view of a three-dimensional function defining the distribution of center weighted weighting coefficients employed in the system of Fig. 1;

Fig. 2b is a diagram of a kernel of weighting functions constructed from the three-dimensional function of Fig. 2a;

Fig. 2c illustrates the use of the kernel of weighting functions of Fig. 2b in a large image array of pixels by the system of Fig. 1;

Figs. 3a and 3b illustrate alternative computations of the sharpening factor K as a function of the center weighted variance V in the system of Fig. 1;

Fig. 4 illustrates the distribution of variance values for uniform, textured and sharp image areas; and

Fig. 5 is a block diagram illustrating an alternative center weighted variance process which may be employed in the system of Fig. 1.

DETAILED DESCRIPTION

Referring to Fig. 1, an original image array, comprising a plurality of digitized image pixels defining a two-dimensional image, is stored in a memory 10, each pixel Z being uniquely identified by a two-dimensional symbol $Z_{i',j'}$. The unsharp masking process, in accordance with well-known techniques, employs a blurring processor 50a which, in essence, averages each pixel received from the memory 10 with all of its neighbors in a small window of pre-defined size, typically 11 pixels by 11 pixels. The result is a blurred pixel which is then subtracted from the original pixel by a subtractor 20. The difference is then multiplied by a sharpening factor K at a multiplier 25, and the product is then added to the original image at an adder 30. The factor K is proportional to the center weighted variance of a small image neighborhood surrounding the pixel of interest. In local image neighborhoods having fairly large variances, $K > 0$, and the result is a sharpened image pixel $Z'_{i',j'}$ which is stored in a memory 35. After all of the image pixels stored in the memory 10 have been thus processed, the array of image pixels in the memory 35 defines a much sharper image than the original array stored in the memory 10.

Reducing the foregoing to an algebraic expression, the system of Fig. 1 constructs the sharpened image Z' from the original and blurred images, Z and $\overline{Z}$ respectively, as follows:

$$(0)\quad Z' = Z + K(Z - \overline{Z}).$$

In one aspect of the invention, it is not always desirable to sharpen the image, particularly in those image areas containing no sharp features, as this would simply boost the noise. The present

invention avoids such pitfalls. For example, in somewhat uniform image neighborhoods K may equal 0 so that Z' = Z in Equation (0), which avoids boosting noise because the output image Z' is simply the original image Z. In perfectly uniform image neighborhoods K may equal -1 so that $Z' = \overline{Z}$ in Equation (0), which achieves noise suppression because the output image Z' is simply the blurred image $\overline{Z}$. The manner in which the invention provides both sharpening and noise suppression in different neighborhoods of the same image is described hereinbelow with respect to Figs. 3b and 3c.

PSEUDO CENTER WEIGHTED VARIANCE PROCESS

In the present invention, the sensitivity of the system of Fig. 1 to sharp features in the original image stored in the memory 10, and the fidelity with which such sharp features are reproduced by the system of Fig. 1, are increased without (as would previously have been expected) unduly accentuating noise in uniform areas of the image (areas not containing sharp features). This is done by computing individual sharpening multiplier coefficients $K_{i',j'}$ for each image pixel $Z_{i',j'}$ processed in the system of Fig. 1 in accordance with the pseudo center weighted variance process. A pseudo center weighted variance processor 40 (hereinafter referred to as the pseudo processor 40) performs the computation. Such a processor may be a software- or firmware-programmed machine or may be a dedicated hard-wired processor.

The pseudo processor 40 comprises two branches. In Fig. 1, the first branch comprises a square function 45 which computes the square of the value of each image pixel $Z_{i',j'}$. This branch

further comprises a blur convolver 50 and an associated center weight look-up table 55. The look-up table 55 stores a two-dimensional kernel of predetermined size (preferably 11 pixels by 11 pixels) comprising weighting coefficients of which the centermost has the greatest amplitude while the outermost weighting coefficients have the smallest amplitudes, there being a continual variation therebetween.

The topology defined by the weighting coefficients stored in the look-up table 55 is illustrated in Fig. 2a. The look-up table 55 stores an 11 x 11 kernel such as that illustrated in Fig. 2b, comprising 11^2 (or 121) weighting coefficients discretely defined at 121 points in an 11 x 11 square array. The blur convolver 50 convolves an 11 x 11 neighborhood of image pixels taken from the original image array memory 10 surrounding the current pixel of interest, $Z_{i',j'}$, with the corresponding weighting coefficients comprising the 11 pixel by 11 pixel square window of weighting coefficients illustrated in Fig. 2b. The blur convolution performed by the blur convolver 50 performs the following process:

$$(1) \quad \sum_{i=i'-m,\ j=j'-m}^{i'+m,\ j'+m} W_{i,j}\, Z_{i,j}^{\;2}/N\ ,$$

where $N = \sum_{i,j} W_{i,j}$ and $m = \frac{n-1}{2}$, where n is the size of the kernel. (Note: n = 11 in the present example.)

The foregoing process is repeated for each pixel in the original image array memory 10, so that the kernel (or "window") of Fig. 2b is, in effect, moved across the two-dimensional image array so as to cover it entirely, one pixel at a time, in the

manner illustrated in Fig. 2c.

Each discrete summation computed by the blur convolver 50 is transmitted to the positive input of an adder 60. The negative input of the adder 60 receives a corresponding result computed in the other branch of the pseudo processor 40.

The other branch of the pseudo processor 40 includes a second blur convolver 50a and a center weight look-up table 55a, preferably identical to the first center weight look-up table 55. The blur convolver 50a operates in a manner identical to the blur convolver 50, except that it receives each image pixel $Z_{i',j'}$ from the original array memory 10 without its being squared. Thus, the blur convolver 50a performs the same process except that it works on an array of unsquared image pixels $Z_{i',j'}$. The blur convolver 50a thus performs the following operation:

$$(2) \quad \sum_{i=i'-m,\,j=j'-m}^{i'+m,\,j'+m} W_{i,j} Z_{i,j} / N$$

Each summation performed by the blur convolver 50a is then transmitted as a discrete value to a square function 45a, which functions in the manner identical to that of square function 45, in that it squares the value it receives. The output of the square function 45a is applied to the negative input of the adder 60 which then outputs, for each pixel $Z_{i',j'}$ in the original image array, a pseudo center weighted variance $V_{i',j'}$.

From the foregoing, it should be apparent that the output of the adder 60 is defined as follows:

$$(3) \quad \sum_{i,j} W_{i,j} (Z_{i,j})^2 / N \; - \; [\sum_{i,j} W_{i,j} Z_{i,j} / N]^2.$$

Each pseudo center weighted variance $V_{i',j'}$ is applied to a look-up table 70 which, in response, furnishes a corresponding sharpening multiplier coefficient $K_{i',j'}$ to the input of the multiplier 25. It should be noted that in the absence the centerweighting feature of the invention, all $w_{i,j} = 1$, and the center weighted variance becomes a standard definition of variance.

In accordance with the invention, the look-up table 70 defines the multiplier coefficient K as a function of the pseudo center weighted variance V, as illustrated in Fig. 3a. Alternatively, Fig. 3b illustrates a somewhat discontinuous way of defining K in terms of V, in that each knee in the curve is really a sharp corner. Other definitions of K as a function of V are perfectly acceptable within the scope of the invention, the central idea being that a greater variance justifies a greater sharpening of the image and therefore a larger value of the sharpening multiplier coefficient K.

A fairly large kernel (11 x 11 pixels) is preferred to avoid blocking artifacts because the "effective" area A_{EFF} in Fig. 2a is reduced due to the decrease in kernel amplitude at the outer pixels.

CALCULATION OF V_1 AND V_2

For a given input image or set of input images having the same noise characteristics, the variances V_1 and V_2 (defining the knees of the curves of Fig. 3) must first be calculated before the image is processed. To calculate V_1, a very uniform area in the image is chosen, and the variance value of each of the pixels in the uniform area is computed. V_1 is the average of all those variance values.

V_2 preferably lies between the typical variance value of textured areas and the typical variance value of sharp edge areas in the same image. Fig. 4 is a graph showing variance values plotted against distribution (number of occurrences) for film grain noise (a "uniform" area) (Curve 14), texture (Curve 16), and sharp edge detail (Curve 18) for a typical digital image produced by scanning a photograph. The typical variance values of "texture" and "sharp edge" image areas correspond to the peaks of the curves 16 and 18, respectively, in Fig. 4. V_2 is adjusted to find the most natural looking rendition of texture area. Typically, this adjustment is done by varying V_2 between the peak variance values of the curves 16 and 18 of Fig. 4 on a trial-by-error basis. Once this optimum value V_2 is found, it remains constant for the entire input image and subsequent input images of the same type.

SHARPENING WITH NOISE SUPPRESSION

Both image sharpening and noise suppression are achieved in different areas of the <u>same</u> image by employing the amplification factor function illustrated in Fig. 3b or 3c. Sharpening occurs for values of $k > 0$ while noise reduction occurs for values of $-1 < k < 0$.

SHARP CENTER WEIGHTED VARIANCE PROCESS

For even greater sensitivity to sharp features in the computation of the center weighted variant, a sharp center weighted variance processor 40' (illustrated in Fig. 4) may be substituted for the pseudo center weighted variance processor 40 in the system of Fig. 1. The sharp center weighted variance processor 40' is virtually identical to the pseudo center weighted variance processor 40, except

that a square function 52 is interposed between the output of the center weight look-up table 55 and the blur convolver 50, so that each center weight coefficient $W_{i,j}$ is first squared, to become $W_{i,j}^2$, and the latter is then furnished to the blur convolver 50. (In a simpler embodiment, the square function 52 is implemented in the look-up table 55.) Thus, the sharp center weighted variance computed at the output of the adder 60 is as follows:

$$(4)\quad \sum_{i,j} W_{i,j}{}^2 (Z_{i,j})^2/N_2 - [\sum_{i,j} W_{i,j} Z_{i,j}/N]^2,$$

where $N_2 = \sum_{i,j} W_{i,j}{}^2$.

The result is that the topology of the weighting coefficients employed in the blur convolver 50 of Fig. 4 is much sharper, corresponding to the dotted line topology suggested in Fig. 2a.

In another variation on Fig. 4, the square function 52 has the ability to raise each weighting coefficient $W_{i,j}$ to any power between unity and 2 (or any other power greater than unity). The power which the variable square function 52 employs is in turn determined by a computation of the pseudo variance by the pseudo variance processor 40, each pseudo variance computed by the pseudo variance processor 40 being applied at a control input 52a of the variable square function 52. Preferably, for smaller values of the pseudo center weighted variance, the variable square function 52 raises $W_{i,j}$ to the minimum power (e.g., unity) while for larger values of the pseudo variance received at its control input 52a, the variable square function 52 raises each center weighted coefficient $W_{i,j}$ to the highest power.

While the invention has been described in

detail with specific reference to the accompanying drawings, variations and modifications may be made without departing from the spirit and scope of the invention.

CLAIMS:

1. An image enhancement processing system which receives an original image comprising an array of pixels, each pixel comprising an amplitude value, said system comprising:

means for storing a mask of weighted coefficients characterized by a centermost coefficient of maximum amplitude and outermost coefficients of minimum amplitudes, said mask corresponding to a local neighborhood within said array of pixels;

means for convolving said mask with local neighborhoods within said array of pixels so as to compute the center weighted variance of a local neighborhood surrounding each one of said pixels;

means, responsive to said means for computing, for replacing the amplitude value of said one pixel with a new value, said new value corresponding to a new image sharpened with respect to said original image to a degree proportional to the amount by which said center weighted variance exceeds a first predetermined value; and

means for storing said new value, whereby said means for storing stores a frame of new pixels representing an enhanced image after said means for computing and said means for replacing have processed all of the pixels in said array.

2. The system of claim 1 wherein said new value corresponds to a new image blurred with respect to said original image to a degree proportional to the amount by which said center weighted variance is less than a second predetermined value less than said first predetermined value.

3. The system of claim 1 wherein said

first predetermined value lies between a variance value typical of textured areas in said original image and a variance value typical of sharp edged areas in said original image.

4. The system of claim 2 wherein said second predetermined value corresponds to the average variance of uniform areas in said original image.

5. An image sharpening processor system, comprising:

I. means for furnishing a plurality of digitized image pixels representing an image;

II. image sharpening means, comprising:

a) means for computing, for each pixel of said image, a blurred pixel comprising a low pass filtered value computed from a group of pixels in said image surrounding said one pixel,

b) first differencing means for computing the difference between said one pixel and the corresponding blurred pixel,

c) means for multiplying the difference computed by said first differencing means by a sharpening factor K to produce a product,

d) adder means for adding said product to said corresponding blurred pixel to produce a sharpened pixel;

III. means for computing a center weighted variance, comprising:

a) means for computing a square of a center weighted mean of each pixel in said image, comprising:

1) look-up table means storing an array of discrete weighting coefficients of which the centermost coefficient in said array has the greatest value while the outermost coefficients in

said array have the smallest values,

2) convolver means operative for each one pixel in said image, for selecting a neighborhood of pixels surrounding said one pixel in said image coincident with said array of weighting coefficients and for multiplying the corresponding pixels in said selected neighborhood by the corresponding weighting coefficients in said array so as to produce a sum of products therefrom for all pixels in said selected neighborhood,

3) first squaring means for computing the square of said first sum of products,

b) means for computing the center weighted mean of the square of each pixel, comprising:

1) second squaring means for computing the square of each pixel in said image,

2) convolver means for defining a neighborhood of squared pixels surrounding said one squared pixel from said image array and for multiplying each pixel in said neighborhood by the corresponding weighting coefficient in said array of weighting coefficients so as to produce a second sum of products,

c) second differencing means for subtracting said second sum of products from said first sum of products so as to produce a center weighted variance corresponding to said one pixel;

IV. look-up table means defining said sharpening coefficient K as a function of said variance whereby said sharpening coefficient K increases as said variance increases over a finite range of said variance, including means for receiving the value of said variance corresponding to said one pixel and transmitting the corresponding

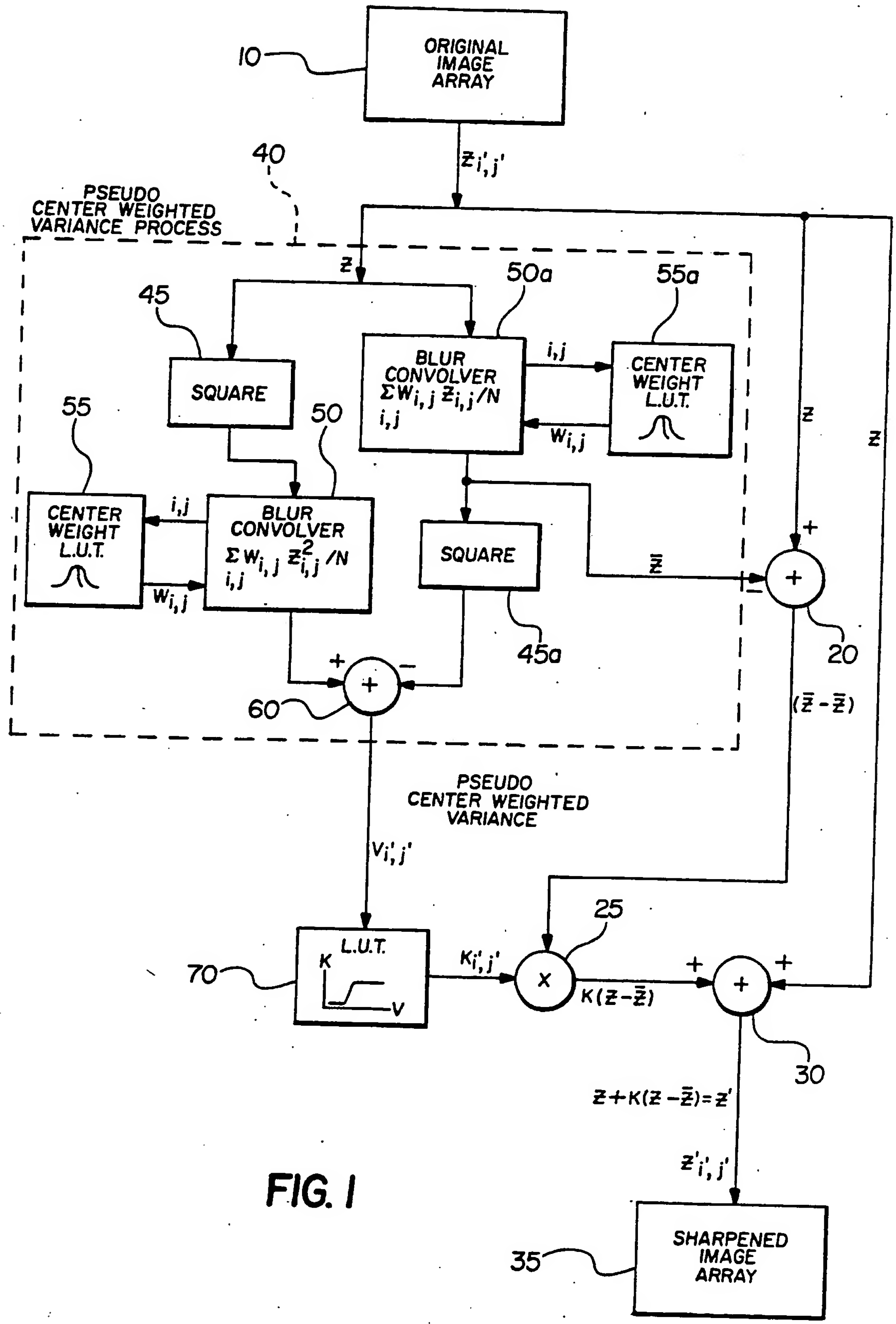
value of said sharpening coefficient K to said adder means.

6. The system of claim 5 further comprising a third squaring function for computing the square of each of said weighting coefficients and then transmitting said square of said weighting coefficient to said second convolver means instead of said weighting coefficient.

7. The system of claim 6 wherein said third squaring means comprises means for raising each of said weighting coefficients to a variable power, said power lying between unity and a selected number greater than unity in proportion to the magnitude received at a control input thereof, said system further comprising means for computing the variance of said one pixel and transmitting said variance to said control input whereby said variable power of said third squaring means increases as said variance increases.

8. The system of claim 5 wherein said look-up table means defining said sharpening coefficient K as a function of said variance transmits a high value of K which results in maximum image sharpening in response to receiving a variance value at least nearly typical of sharp edge areas of said image and transmits a low value of K which results in maximum image blurring in response to receiving a variance value at least nearly typical of uniform areas of said image, whereby said system performs both image sharpening and noise suppression in the same image.

9. The system of claim 8 wherein said high value of K is greater than unity while said low value of K is less than zero.


ORIGINAL IMAGE ARRAY
10
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PSEUDO CENTER WEIGHTED VARIANCE PROCESS
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SQUARE
50a
BLUR CONVOLVER
55a
CENTER WEIGHT L.U.T.
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CENTER WEIGHT L.U.T.
50
BLUR CONVOLVER
SQUARE
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L.U.T.
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25
30
SHARPENED IMAGE ARRAY
35

FIG. I

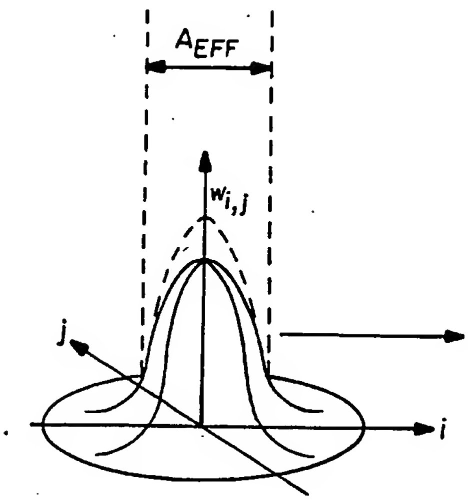


FIG. 2A

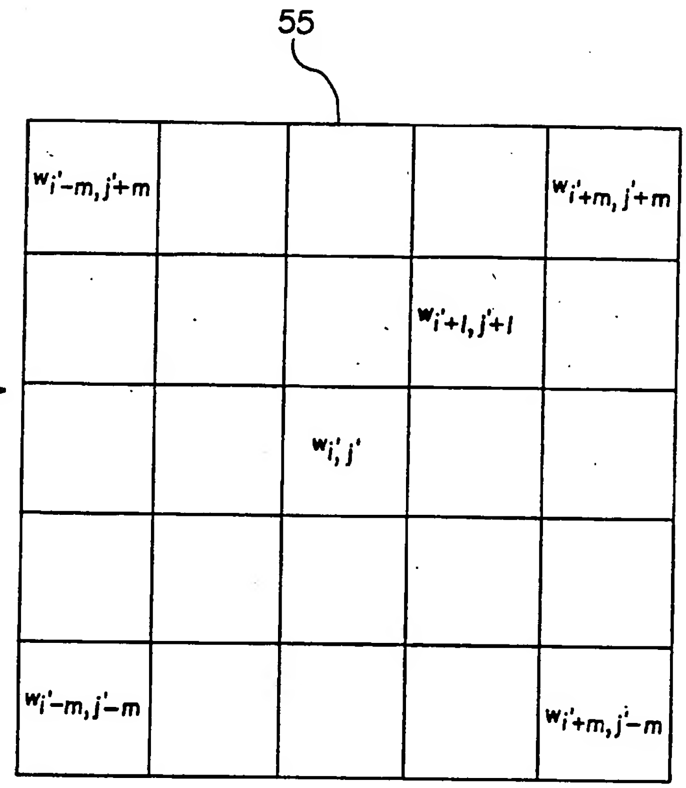


FIG. 2B

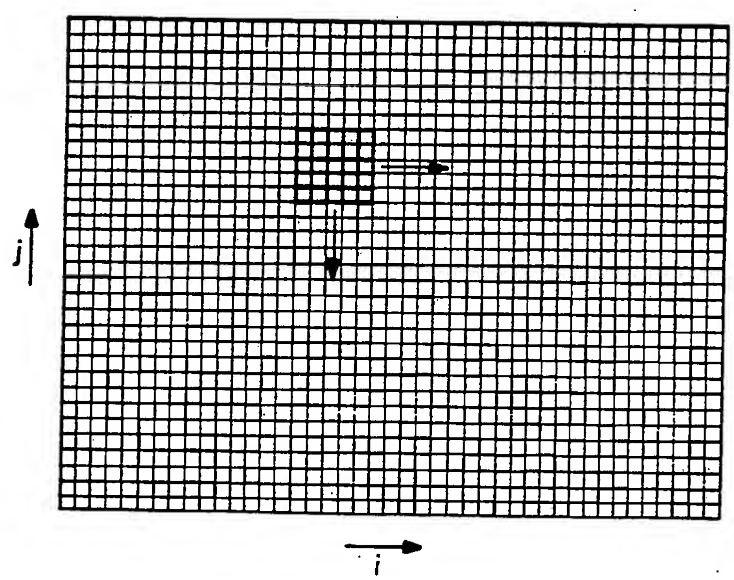


FIG. 2C

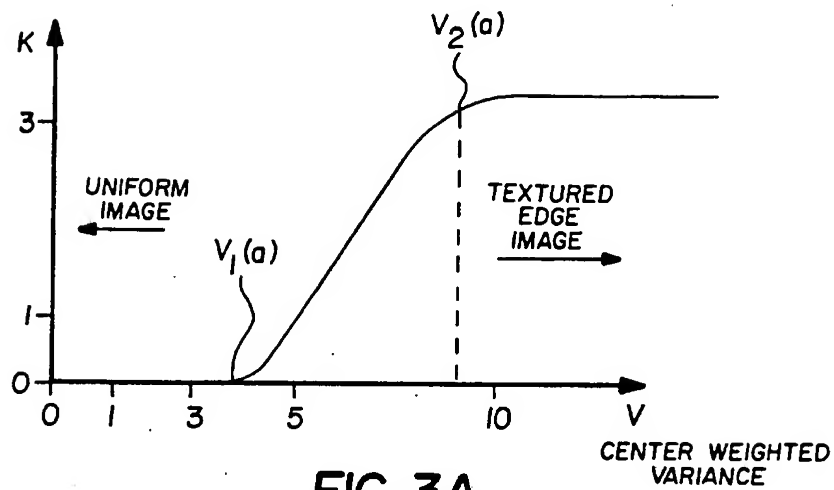


FIG. 3A

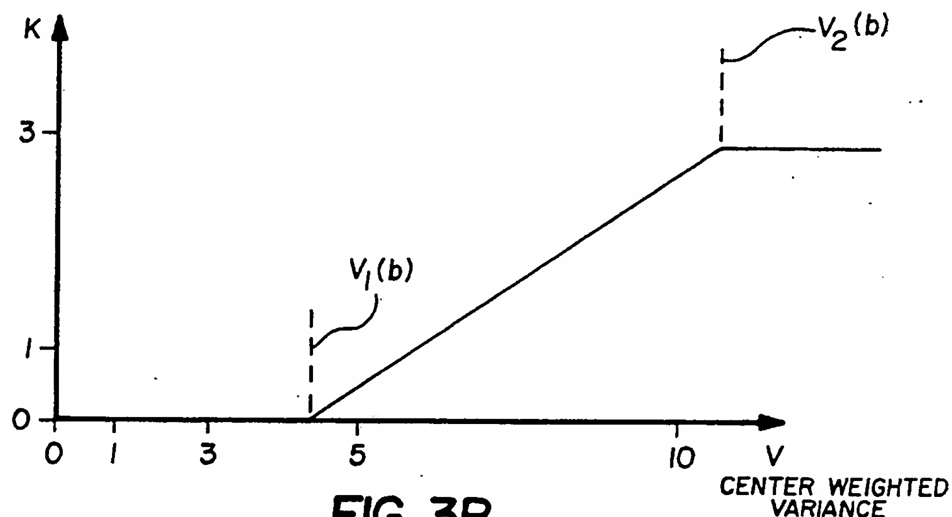
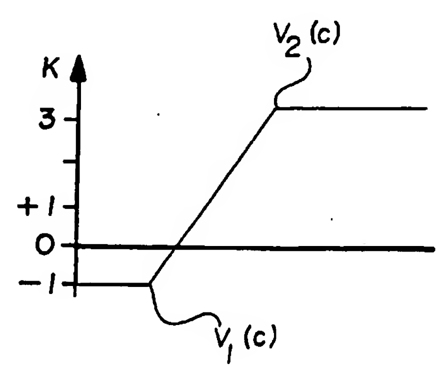


FIG. 3B

FIG. 3C



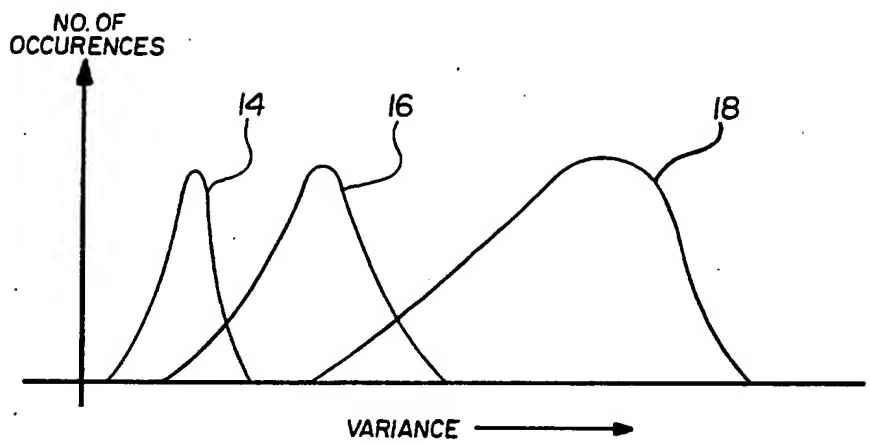
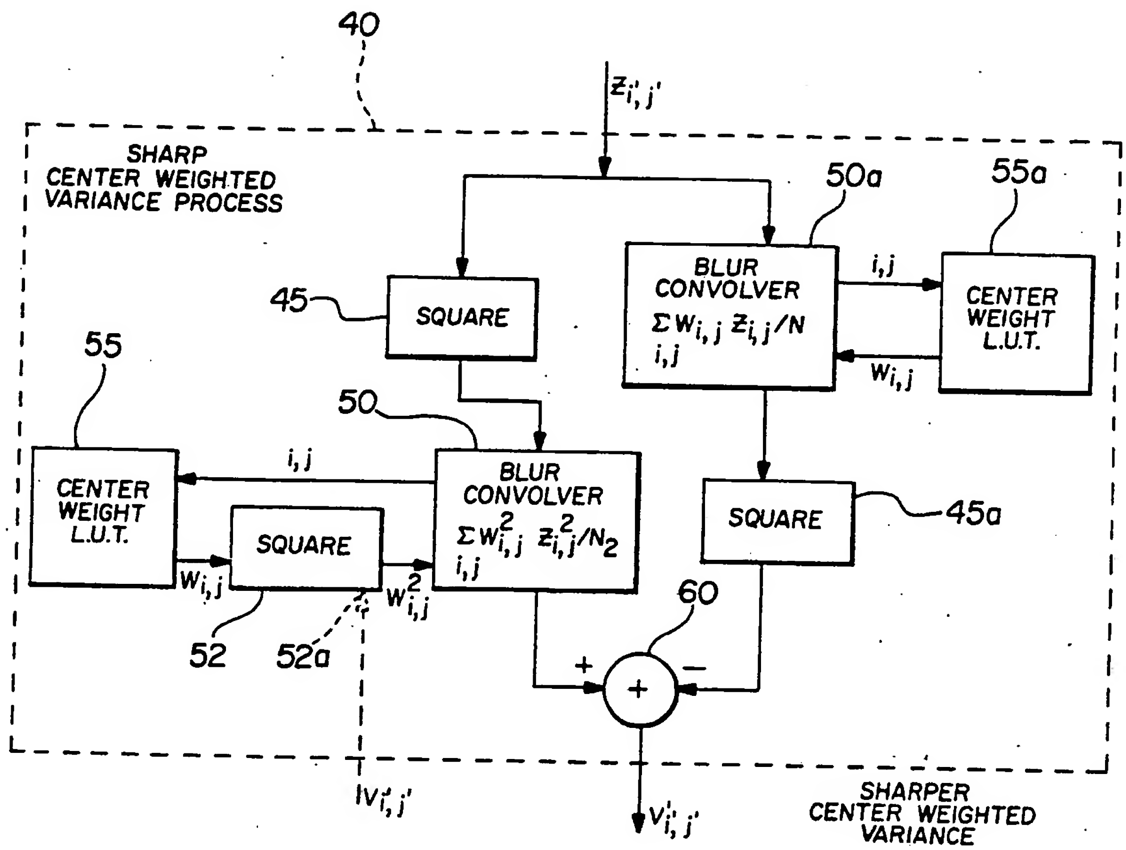


FIG. 4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$z_{i',j'}$
SHARP
CENTER WEIGHTED
VARIANCE PROCESS
50a
55a
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CONVOLVER
$\Sigma W_{i,j} z_{i,j}/N$
i,j
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CONVOLVER
$\Sigma W^2_{i,j} z^2_{i,j}/N_2$
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SQUARE
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SQUARE
45a
60
52
52a
+
−
+
$IV_{i',j'}$
$V_{i',j'}$
SHARPER
CENTER WEIGHTED
VARIANCE

FIG. 5

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 89/05702

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [8]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: G 06 F 15/68

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC5	G 06 F

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US, A, 4571635 (A.B. MAHMOODI ET AL) 18 February 1986, Cited in the application --	1-9
A	US, A, 4315318 (H. KATO ET AL) 9 February 1982, Cited in the application -- --------	1-9

* Special categories of cited documents: [10]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
19th March 1990	05.04.90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	L. ROSSI

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. PCT/US 89/05702

SA 33247

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 28/02/90
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
US-A- 4571635	18/02/86	EP-A-	0153167	28/08/85
		JP-A-	60192482	30/09/85
US-A- 4315318	09/02/82	DE-A-C-	2952426	04/09/80
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		JP-A-	56075137	22/06/81
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